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ABSTRACT

Students in grades four and eight were given parallel forms of mathematics subtests of Iowa Tests of Basic Skills, once using calculators and once without. Performance with calculators was compared to performance on regular administration of subtests. In both grades, mean scores on problem solving and computation subtests were significantly higher with calculators, but no difference was found for the concepts subtest. Largest differences appeared on computation subtests. For fourth grade, significant improvement in subtraction and multiplication occurred with calculators. Eighth graders' performance on whole number and decimal operations was significantly improved by using a calculator, but their performance on operations involving fractions was significantly worse with calculators. In both grades, students completed fewer items on the computation and problem-solving subtests when they used calculators. Correlations between scores on the two testings were computed for the three subtests. After correction for restriction in range and attenuation, the resulting correlations ranged from .79 to .99 for fourth grade and from .96 to 1.0 for eighth grade. This suggests that if the tests were standardized with calculators, the rankings of students, at least in eighth grade, would be the same as the rankings given by the present mathematics subtests. (Author/MP)

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The Effect on Pupil Performance of Using Hand-held Calculators on Standardized Mathematics Achievement Tests

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Paper presented at the
Annual Meeting of
the National Council on Measurement in Education
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The Effect on Pupil Performance of Using Hand-held Calculators on Standardized Mathematics Achievement Tests

The use of electronic calculators by students has been an issue in mathematics education for several years. Bell (1978) quoted a 1975 report by the National Advisory Committee on Mathematical Education which recommended that, at least by the eighth grade, every student be allowed to use a calculator during all of their mathematical work, including tests. The effect on achievement from using calculators during mathematics instruction has been studied frequently. Roberts (1980) listed over thirty journal articles and doctoral dissertations dealing with the effect of instruction involving electronic calculators. However, the effect of using calculators during the testing situation has been examined less often.

During the 1977-78 mathematics assessment of the National Assessment of Educational Progress, a special booklet was designed to examine the effect of using calculators (Carpenter, Corbitt, Kepner, Lindquist, & Reys, 1981a, 1981b). Students ages 9, 13, and 17 were required to use a calculator to solve approximately 25 exercises. Other students solved the same problems using only paper-and-pencil methods. The same amount of time was allowed for each exercise no matter which format was used. The scores of all three age groups when using calculators for routine calculation involving subtraction, multiplication, and division were superior to the scores produced with paper-and-pencil procedures. On addition problems the scores produced with calculators were slightly larger than scores achieved with paper-and-pencil. Students also seemed

to respond more slowly and to omit more items when using the calculator. When the concept needed for problem solving was not clearly understood, the availability of a calculator was of little or no help and sometimes even detrimental. Application problems involving nonroutine computation, division with remainders, decimals, and percents were not improved by using calculators.

Kasnic (1978) found in a study of sixth graders that there was no significant difference between low and high ability groups on a test of problem solving ability when low ability students were allowed to use calculators during the test. Kasnic concluded that students with low ability in problem solving can benefit from using calculators on tests of problem solving. Similarly, Andersen (1977) found that calculators were beneficial to students during the testing process. In a study involving seventh grade students, mathematics classes were randomly assigned to receive 20 weeks of similar instruction using either calculators or paper-and-pencil methods. The experimental and control groups did not differ significantly on either pretest or posttest measures of overall mathematics achievement when no calculators were used during testing. However, students who used calculators during instruction were allowed to use them during one posttest of computation. Andersen reported that the students using calculators solved about 50 percent more single-step problems during a timed test and approximately 40 percent more multiple-step problems than students who did not use calculators. He also stated that when adequate time was

allowed for all students to finish, students using calculators solved problems correctly at about twice the rate of pupils using paper-and-pencil computation. In a study comparing a calculator curriculum in ninth grade general math to a non-calculator curriculum, Hopkins (1979) allowed half of each treatment group to use calculators on a standardized posttest. These students achieved higher scores on the posttest (the computation and application sections of the Stanford Achievement Test, Intermediate Level II, Form B) than students without calculators.

At the college level, students who used calculators on in-class chemistry examinations scored better even when the students did not differ in ability level (Sosebee & Walsh, 1975). One series of articles (Roberts & Fabrey, 1978; Roberts & Glynn, 1978a, 1978b; Roberts & Lerner, 1978; and Roberts, Seaman & Lerner, 1978) focused directly on the effect of using a calculator on computation. They reported that using a calculator improved the number of correctly solved problems, shortened the time to work the problems, and increased efficiency. Amount of prepractice did not affect the result, but instructions to work fast or to work accurately did produce different outcomes. More correct answers, longer working times, and less efficient problem solving were produced by the instruction to work accurately.

However, Shult (1980) tested a group of sixth graders following six weeks of calculator-assisted instruction in problem solving. The students were tested both with and without calculators. Shult found

no significant difference in the time to solve problems, accuracy, frequency of trial and error strategy, range of problem solving processes, or logical errors in strategy between students taking the test with calculators and those who worked unaided.

The present study investigated the effect of using electronic calculators on achievement in standardized tests of computation, mathematical problem solving, and mathematical concept usage. In particular, the effect of the calculator on simple whole number, decimal, and fraction problems was studied.

Method

Students in grades four and eight of the Iowa City, Iowa Public Schools participated in the study. The mathematics concepts, problem solving, and computation subtests of Iowa Tests of Basic Skills (Hieronymus, Lindquist, & Hoover, 1978) were used to measure mathematics achievement. For each of the three test areas, four classrooms, approximately 90 students, were selected from each grade with a total of 539 students participating. The students received a short presentation about using a TI-1000 hand-held calculator. The presentation included clearing the calculator, entering whole numbers, and computation with all four operations. The eighth graders also worked problems involving decimals. The students were told how to tell if the calculator was not operating correctly. Malfunctioning calculators were replaced immediately. After the presentation, students in the eighth grade completed one of the three mathematics subtests of Form 8 of the Iowa Tests of

Basic Skills (ITBS) using a calculator. Fourth grade students completed one of the Form 8 mathematics subtests using a calculator within two days after the instruction. The students were told that the use of the calculators was optional. Following the test, the students completed the short questionnaire shown in Table 1 regarding their use of calculators. These students' results were also obtained for the regular administration of the ITBS using the alternate form (7) taken without the use of calculators. The administration of the tests using calculators took place on October 1-3, 1980 and October 13-17, 1980. The regular ITBS administration for the Iowa City school system was October 6-10, 1980. The study was counterbalanced so that half of the students in each grade took the alternate form with calculators the week prior to the regular testing, and the other half took it the week after the regular testing. Grades four and eight were chosen because the grade four tests were composed almost entirely of problems using whole numbers, while in the grade eight tests a large number of the problems involved fractions and decimals.

Analyses

The means from the regular administration were compared to the means from the special administration within each subtest and grade using dependent measures t tests. To analyze more specific effects, item analyses were performed by grade on both forms of each of the subtests. The average item difficulties for particular categories of items were computed. Completion rates on each subtest were also examined for both grades. The difference between each student's score

on the regular administration and the corresponding score on the calculator administration was calculated. Correlations between scores on the concepts subtest and these difference scores for both the problem solving and computation subtests were examined to see if achievement in mathematics concepts might be related to the direction and amount of score difference in computation and problem solving between the two test administrations. Concepts scores from the regular administration were used for these analyses. The differences were also used to compute correlations with reported familiarity with calculators and with amount of calculator usage during the test.

Results

The mean grade-equivalent scores resulting from the two administrations are shown in Table 2. National norms were used to obtain the grade equivalents. The mean scores on the administration with calculators were significantly higher than the scores on the regular administration for the problem solving and the computation subtests in both grades.

The correlation between the scores on the two administrations was computed. Because the Iowa City population was known to be less variable in achievement than the national standardization sample, a correction for restriction in range was made in the correlation between the two administrations in the Iowa City sample. Then the resulting correlation was corrected for attenuation (Lord & Novick, 1968). The resulting standard deviations and reliability coefficients are shown in

Table 3. In the concepts subtest for grade four and in all subtests for grade eight, the corrected correlation was approximately 1.00. This suggests that if the mathematics subtests were standardized with calculators, the ranking of the students, at least in eighth grade, would be the same as the ranking given by the present mathematics subtests.

Item analyses were performed on the results of the regular administration and the results of the special administration with calculators. Because Form 7 of the Iowa Tests of Basic Skills was used in the regular administration and the parallel form (8) was used in the special administration, the results of the item analyses could not be compared directly. Instead, the two administrations were compared to a sample used in the original equating of the two forms (Oberly, 1979) in which one group of students took both forms of each subtest. Item means and rate of completion were examined. Over 90 percent of both the fourth grade group and the eighth grade group completed the mathematics concepts subtest whether the calculator was used or not. However, the students indicated that they used the calculators for only a few items on the concepts subtest. The completion rate on the problem solving subtest was much lower. Fifty-three percent of the fourth graders completed the entire subtest when the calculator was available compared to 90 percent with paper-and-pencil methods. Only 16 percent of the eighth graders using calculators completed the subtest compared to 94 percent on the regular administration. On the computation subtest,

the completion rates were 41 percent with calculators versus 62 percent without calculators for fourth grade, and 55 percent with calculators versus 83 percent without calculators for eighth grade. In the equating sample, the completion rates on both forms were similar to the completion rates on the regular administration in the Iowa City sample.

The mean item difficulties for various item types in each subtest are shown in Tables 3 to 6. On the concepts subtest (Table 4), having a calculator available seemed to reduce the item averages for fourth graders and to increase the eighth graders' item averages in all areas except geometry and measurement. However, the differences tended to be small. The differences from using a calculator were also small on the problem solving subtest (Table 5), but on problems involving single-step addition or subtraction for fourth grade and single-step multiplication or division for eighth grade, the scores on the administration with calculators were significantly larger. On the problem solving subtest there were also large differences in rate of completion. Even though fewer items were completed with the calculator available, the item means for fourth grade were at least as high as the means on the regular administration. The computation subtest showed the largest differences. The difference for fourth grade (Table 6) was mainly due to the significant improvement in subtraction and multiplication with a calculator. Since all the division problems appeared in the latter half of the fourth grade test, many students were not able to attempt these items. The average completion rate in fourth grade for

division problems was 72 percent on the regular administration and 57 percent with calculators. In the eighth grade, average item difficulties for whole number and decimal operations on the computation subtest were significantly larger with a calculator. Most of the gain in whole number operations occurred in subtraction and multiplication items. However, eighth graders' performance on computations involving fractions was significantly worse with a calculator. Some of the decrease for fraction items was due to a much larger rate of omitting these items when the calculator was available. The choice of "not given" was not increased. Apparently the students did not know how to work fraction items with a calculator and just omitted them.

The percentage of correct answers for certain types of items on the computation subtest was particularly small when the calculator was available. For fourth grade, a division problem which asked for a whole number remainder was answered correctly by only 9 percent of the students having calculators. During the administration of the computation subtest with calculators, many fourth grade students questioned the administrator about the problem 58 - 29 = . Since the answer was identical to the subtrahend, many students assumed that the calculator had malfunctioned. As previously noted, in eighth grade, performance of computations with fractions was impaired when a calculator was available.

Other items were especially improved by having a calculator available. Operations involving large numbers on decimals were aided by a

calculator. Subtraction which required borrowing and division without remainders was also improved in the calculator groups.

Questionnaires describing their use of calculators were completed by 98 percent of the fourth grade group and 87 percent of the eighth grade group following the administration of the test using calculators. A summary of the results of the questionnaires (Table 1) provided some background information for interpreting the results of the study. Hand-held calculators were not new to these students. Seventy-seven percent of the fourth graders and 89 percent of the eighth graders reported using hand calculators at least occasionally outside of school. The students were told prior to taking the test that they need not use the calculator on every item and that some items could be answered more easily without a calculator. Most students answered some items without using the calculator. For example, 97 percent of the students in both grades who completed the questionnaire after taking the concepts subtest reported that they either did not use the calculator or only used it for a few items. All the students used the calculator to some extent during the problem solving subtest with 79 percent of the eighth graders and 48 percent of the fourth graders indicating that they used the calculator on most problems. For computation all of the eighth graders used the calculators to some extent, and 79 percent used it on most problems. For fourth grade, 99 percent of the students used the calculator on the computation subtest with 59 percent reporting that they used it on most problems. Twelve percent of the fourth graders and nine percent of the eighth graders reported that their calculators

did not work properly during the test administration. Removing these students from the analyses did not change the outcome.

There were no relationships between differences computed from the students' two scores and either familiarity with calculators or amount of calculator usage during the test which were significant at $p = .05$. At the eighth grade level there was a small relationship ($r = .20$, $p < .10$) between positive change in score with a calculator and increased usage of the calculator during the problem solving and computation subtests. All other coefficients were close to zero. For fourth grade the differences between the two administrations of the problem solving and computation subtests were uncorrelated with achievement on the mathematics concepts subtest. For eighth grade there was no relationship between the difference on the problem solving subtest and achievement on the concepts subtest, but there was an inverse relationship of $-.54$ ($p < .001$) between concepts achievement and increase in computation score when a calculator was available.

Discussion

The results of this study tended to support the conclusions drawn from the National Assessment of Mathematics (Carpenter et al., 1981a, 1981b). The rates of completion for both fourth and eighth grade were much lower on the problem solving and computation subtests when calculators were available. The rate of completion was unchanged on the concepts subtest, but the students indicated that they used the calculator only slightly for that subtest. These results agreed with the

report of slower response on computation with calculators in the National Assessment. Andersen (1977) and Shult (1980) did not find a reduced rate of response, but both of these studies involved several weeks of instruction with calculators prior to the assessment. Increased understanding of how to use a particular calculator and specific instruction in methods of computation for calculators might improve the rate of completion.

Scores on the computation subtest were increased significantly in ($p < .005$) both grades by using a calculator. Smaller differences favoring the calculator administration appeared for the problem solving subtest. For fourth grade most of the improvement in computation was in multiplication and subtraction. Subtraction which required borrowing, division without remainders, and multiplication with large numbers were areas particularly aided by having a calculator available. These were areas in which fourth graders had been instructed but might not have gained mastery. Eighth graders' scores were larger in all areas when calculators were available except whole number division and operations involving fractions. The pretest instruction presentation did not include specific instruction for computations with fractions or division with whole number remainders. The students apparently did not consider converting the fractions to decimals and then computing a solution or using paper-and-pencil methods. Instead, they omitted many more of these items than other items. If calculators are to be used in mathematics testing, instruction should include computation

procedures particular to calculators. In general, when the students understood the concept, having a calculator improved the students' accuracy. However, when the concept was unclear or specific procedures necessary for computation on a calculator were unknown, having a calculator did not help and sometimes resulted in significantly lower scores than on the regular administration.

Eighth grade students with lower scores on the concepts subtest improved their computation scores with a calculator more than students scoring high on the concepts subtest. However, the relative ranking within the class on computation as shown by the correlation between the two testings was unchanged by calculator use.

Summary

The results of this study suggest two conclusions. First, using calculators while taking standardized achievement tests in mathematics concepts, problem solving, and computation produces differences in the mean scores and in the rates of completion for fourth grade and eighth grade students. Consequently, for the results to be valid on the current editions of the tests, all students must adhere to the administration procedures used in the standardizations. Likewise, if the tests were standardized with calculators, then all students would need to take the tests with calculators available for the results to be valid. Secondly, at least in eighth grade, the correlations between the regular administration and the administration with calculators are practically 1.00 when corrected for attenuation and restriction in

range. As a result, the effect of using calculators on the tests becomes a standardization issue. Except for errors of measurement, pupil percentile ranks would be the same regardless of the standardization method used.

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TABLE 1

QUESTIONNAIRE COMPLETED AFTER THE EXPERIMENTAL TESTING

1. Do you think your calculator worked properly throughout the test?

	4th			8th		
	Concepts	Problem Solving	Computation	Concepts	Problem Solving	Computation
1. Yes	91.7%	88.5%	82.7%	95.0%	89.7%	88.0%
2. No	8.3	11.5	17.3	5.0	10.3	12.0

2. How often have you used hand calculators in your mathematics classes?

	4th			8th		
	Concepts	Problem Solving	Computation	Concepts	Problem Solving	Computation
1. At least once a week	3.6	5.2	17.3	6.3	9.2	1.3
2. About once a month	1.2	4.2	4.9	2.5	8.0	4.0
3. Only once or twice a year	8.3	10.4	32.1	20.0	29.9	20.0
4. Never	86.9	80.2	45.7	71.3	52.9	74.7

3. How often do you use hand calculators outside of school?

	4th			8th		
	Concepts	Problem Solving	Computation	Concepts	Problem Solving	Computation
1. At least once a week	32.1	28.1	28.4	30.0	29.9	18.7
2. About once a month	28.6	24.0	25.9	43.8	35.6	53.3
3. Only once or twice a year	23.8	18.7	22.2	17.5	18.4	21.3
4. Never	15.5	29.2	23.5	8.8	16.1	6.7

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4. How did you use the calculator during the test?

	4th			8th		
	Concepts	Problem Solving	Computation	Concepts	Problem Solving	Computation
1. I used it for all problems.	0.0	20.2	13.5	0.0	7.0	5.3
2. I used it for most problems.	2.4	47.9	59.3	2.5	79.1	73.7
3. I only used it for a few of the problems.	57.8	31.9	24.7	81.0	13.9	16.0
4. I did not use the calculator.	39.8	0.0	2.5	16.5	0.0	0.0

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TABLE 2

NATIONAL GRADE-EQUIVALENT MEANS

	Grade 4			Grade 8		
Subtest	Concepts	Problem Solving	Computation	Concepts	Problem Solving	Computation
No. of Subjects	84	99	81	87	111	77
Mean on Regular Administration	60.1	45.6	46.4	107.8	94.9	88.5
Standard Deviations on Regular Administration	10.38	11.99	8.38	18.07	14.92	12.10
Mean on Testing with Calculator	59.1	47.8	53.1	108.3	98.5	92.0
Standard Deviations on Testing with Calculator	11.34	12.83	8.84	17.49	13.88	8.31
t values	.78	- 2.01*	- 8.55***	- .91	- 3.17**	- 3.48***

Note: All tests are two-tailed. Negative t values favor the testing with calculators.

* $p < .05$ ** $p < .005$ *** $p < .001$

TABLE 3

RELIABILITY - FORMS 7 & 8

	GRADE 4			GRADE 8		
Subtest	Concepts	Problem Solving	Computation	Concepts	Problem Solving	Computation
Sample S.D.	10.38	11.99	8.38	18.07	14.92	12.10
National Standardization SD	12.25	12.24	8.13	19.37	19.73	15.06
National Equivalent Forms Reliability	.822	.819	.827	.874	.781	.793
Sample r	.764	.638	.673	.888	.677	.685
Sample r Corrected for Restricted Range	.813	.646	.662	.900	.772	.760
Sample r Corrected for Attenuation	.989	.789	.800	1.030	.988	.958

TABLE 4

MEAN ITEM DIFFICULTIES ON THE CONCEPTS SUBTESTS

GRADE FOUR									
	FORM 7				FORM 8				Change in Score * $Dif_C - Dif_R$
	No. of Items	Regular Administration	Equating Sample	Difference R	No. of Items	With Calculator	Equating Sample	Difference C	
Numeration, Number Systems, Sets	11	.80	.68	.12	9	.85	.76	.09	-.03
Equations, Inequalities, Number Sentences	4	.69	.66	.03	3	.80	.75	.05	.02
Whole Numbers	7	.71	.59	.12	9	.71	.61	.10	-.02
Fractions	4	.71	.63	.08	4	.66	.61	.05	-.03
Geometry, Measurement	6	.76	.65	.11	7	.49	.44	.05	-.06

R = Regular Administration
C = Calculator Administration

GRADE EIGHT									
	FORM 7				FORM 8				
Numeration, Number Systems, Sets	7	.74	.61	.13	7	.70	.57	.13	.00
Equations, Inequalities, Number Sentences	5	.72	.63	.09	4	.74	.57	.17	.08
Whole Numbers	4	.76	.64	.12	4	.81	.66	.15	.03
Fractions	7	.76	.64	.12	8	.71	.55	.16	.04
Decimals, Currency, Percent	11	.79	.66	.13	11	.78	.62	.16	.03
Geometry, Measurement	10	.63	.52	.11	10	.58	.48	.10	-.01

* This column compares the scores with calculators to scores on the regular administration. Positive scores favor the calculator administration.

TABLE 5

MEAN ITEM DIFFICULTIES ON THE PROBLEM SOLVING SUBTESTS

GRADE FOUR									
	FORM 7				FORM 8				Change in Score* $Dif_C - Dif_R$
	No. of Items	Regular Administration	Equating Sample	Difference R	No. of Items	With Calculator	Equating Sample	Difference C	
Single-Step: Addition & Subtraction	13	.58	.66	-.08	10	.66	.68	-.02	.06**
Single-Step: Multiplication & Division	4	.44	.51	-.07	7	.44	.49	-.05	.02
Multiple-Step	8	.50	.55	-.05	8	.51	.55	-.04	.01

R = Regular Administration
C = Calculator Administration

GRADE EIGHT									
	FORM 7				FORM 8				
Single-Step: Addition & Subtraction	3	.61	.57	.04	4	.61	.58	.03	-.01
Single-Step: Multiplication & Division	5	.64	.62	.02	9	.58	.50	.08	.06***
Multiple-Step	24	.61	.59	.02	19	.55	.53	.02	.00

* This column compares the scores with calculators to scores on the regular administration. Positive scores favor the calculator administration.

** $p < .01$, *** $p < .05$ using dependent measures t test.

TABLE 6

MEAN ITEM DIFFICULTIES
FOR COMPUTATION SUBTEST

GRADE FOUR									
	FORM 7					FORM 8			
	No. of Items	Regular Administration	Equating Sample	Difference R		No. of Items	With Calculators	Equating Sample	Difference C	Change in Score * $Dif_C - Dif_R$
Whole Number Addition	13	.76	.74	.02		13	.80	.75	.05	.03
Whole Number Subtraction	13	.63	.63	.00		13	.81	.64	.17	.17 **
Whole Number Multiplication	12	.51	.60	-.09		12	.76	.60	.16	.25 **
Whole Number Division	4	.38	.48	-.10		4	.45	.51	-.06	.04

* This column compares the scores with calculators to scores on the regular administration. Positive scores favor the calculator administration.

** $p < .001$ using dependent measures t test.

R = Regular Administration
C = Calculator Administration

TABLE 7

MEAN ITEM DIFFICULTIES ON THE COMPUTATION SUBTESTS

GRADE EIGHT									
	FORM 7				FORM 8				Change in Score * $Dif_C - Dif_R$
	No. of Items	Regular Administration	Equating Sample	Difference R	No. of Items	With Calculators	Equating Sample	Difference C	
Whole Number Addition	3	.77	.79	-.02	3	.80	.76	.04	.06
Whole Number Subtraction	3	.73	.74	-.01	3	.85	.66	.19	.20
Whole Number Multiplication	3	.68	.70	-.02	3	.86	.69	.17	.19
Whole Number Division	2	.78	.68	.10	2	.73	.64	.09	-.01
Addition With Fractions	3	.48	.58	-.10	3	.39	.54	-.15	-.05
Subtraction With Fractions	3	.47	.53	-.06	3	.38	.57	-.19	-.13
Multiplication With Fractions	5	.50	.58	-.08	5	.37	.58	-.21	-.13
Division With Fractions	4	.47	.55	-.08	5	.26	.44	-.18	-.10
Decimal Addition	4	.78	.78	.00	4	.70	.60	.10	.10
Decimal Subtraction	4	.74	.74	.00	4	.81	.69	.12	.12
Decimal Multiplication	5	.55	.60	-.05	5	.68	.52	.16	.21
Decimal Division	6	.43	.43	.00	5	.45	.33	.12	.12
Whole Number Operations	11	.74	.73	.01	11	.82	.69	.13	.12**
Operations With Fractions	15	.48	.56	-.08	16	.34	.53	-.19	-.11**
Decimal Operations	19	.60	.61	-.01	18	.65	.52	.13	.14**

R = Regular Administration
C = Calculator Administration

* This column compares the scores with calculators to scores on the regular administration. Positive scores favor the calculator administration.

** $p < .001$ from two-tailed dependent measures t test